Available online at www.sciencedirect.com
ScienceDirect
Journal of the Franklin Institute 343 (2006) 352–360
Journal of The Franklin Institute
www.elsevier.com/locate/jfranklin

Performance analysis of Internet applications over an adaptive IEEE 802.11 MAC architecture

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Received 4 February 2006; accepted 4 February 2006

Abstract

This paper investigates the performance of Internet applications such as web browsing over an adaptive prioritized IEEE 802.11 MAC architecture. In this work, we investigate the consequences of applying these adapters on www and e-mail applications besides the video conferencing application. OPNET is used to simulate several scenarios of WLANs operating at 1 and 2 Mbps transmission rate. By means of throughput, media access delay, http object response, end-to-end delay and other metrics, the performance of the network under study is being evaluated. The results show an outstanding performance for these adapters and in particular under the CWA (contention window adapter) compared to the original IEEE 802.11 standard. On the other hand, the results also show that the operation at high loads will have drastic effects on http application which manifest itself in very low throughput for such application.

Keywords: WLAN; QoS; IEEE 802.11; Adaptive MAC

1. Introduction

Over recent years there has been tremendous growth in wireless communications. This growth also encompasses the personal and business computing. The original IEEE 802.11 [1,2], standard was basically built to support data applications over contention-based access control protocol. As the use of multimedia applications increased it became obvious that WLANs support real-time applications with quality of service (QoS) guarantees the

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0016-0032/$30.00
doi:10.1016/j.jfranklin.2006.02.003

same as their wired counterpart. Recently, many researchers have investigated this issue and proposed several mechanisms to tackle this problem. The focus was on developing adaptive schemes working on top of the existing distributed access control. The most important motivation for this approach is that the widely used wireless adapters are mainly supporting the distributed scheme. Then, by using simple software, the access control scheme can be adapted to the needs of the network. Further, it was stated in [3] that distributed medium access control (MAC) with QoS is more flexible and effective than the centralized MAC, as the dominant operational mode in IEEE 802.11 LANs is the distributed coordination function (DCF) mode [4]. Also many recent research shows that point coordination function (PCF) performs poorly either alone or incorporated with DCF mode. The contribution of this work is focused on analyzing the performance of Internet applications besides video conferencing using the prioritized adapters suggested in [3]. To the best of our knowledge, this work is the first in analyzing and discussing the influence of these adapters on Internet applications. Previous works were general in nature, assuming either general prioritized flows of packets as in [3] or real-time and non-real time applications without considering the unique traffic characteristics of www or e-mail applications as in [5].

This paper is organized as follows. In Section 2 details of IEEE 802.11 are present. In Section 3, we describe the various adapters that can be implemented over MAC core of WLAN proposed in [3]. In Section 4, we describe our implementation. Results are presented and discussed in Section 5. Further conclusion and references follow.

2. IEEE 802.11 MAC architecture [1]

The wireless LAN protocol is based on the IEEE 802.11 series of standards. The standard defines a MAC sublayer and three physical (PHY) layers. The architecture of the IEEE 802.11 WLAN is designed to support a network where most decision-making is distributed across the mobile stations.

2.1. Media access control

The IEEE 802.11 MAC supplies the functionality needed to provide a reliable delivery mechanism for user data over wireless media. The first function of the WLAN MAC is to provide a reliable data delivery service to the users. This is achieved through a frame exchange protocol at the MAC level. The second function of the WLAN MAC is to provide a fair mechanism to control access to shared wireless media. The WLAN MAC performs this function through two different access mechanisms:

(a) A contention-based mechanism, called the DCF.
(b) A centrally controlled access mechanism, called the PCF.

2.2. MAC frame exchange

The minimum MAC frame exchange consists of two frames: a data frame sent from the source to the destination and an acknowledgement (ACK) frame sent from the destination to the source. If the source does not receive an ACK, it tries to retransmit the data frame after it observes appropriate deference. There are retry limits associated with the frame retransmission.

The protocol also suggests an optional use of request to send (RTS) and clear to send (CTS) frame exchanged between source and destination stations for media reservation. RTS is transmitted from the source station to the destination station and CTS is a response initiated by the destination station to the source station. This initial handshake is followed by the minimal MAC frame exchange.

2.3. Basic access mechanism

The basic access mechanism is a carrier sense multiple access with collision avoidance (CSMA/CA) with binary exponential backoff. This access mechanism does not include collision detection functionality.

DCF is a basic access mechanism described in the protocol. It uses physical and virtual carrier sense mechanism. If both mechanisms indicate that the medium is not in use for an interval of DIFS (distributed inter-frame space), the station starts transmitting the frame. If the medium is busy, however, the backoff algorithm is applied. The transmission is considered unsuccessful if no ACK is received from the destination. This may result in the retransmission of the frame. All asynchronous traffic uses the DCF.

The centrally controlled access mechanism uses a polling and responses protocol to eliminate the possibility of contention for the medium. This access mechanism is called the PCF. A point coordinator (PC) controls the PCF. The PC is always located in an AP. In PCF operation, stations ask the PC to register them on a polling list. The PC then regularly polls the stations for traffic while delivering the traffic to the stations. The PCF is an optional part of the IEEE 802.11 standard that is built over the DCF and operates simultaneously with DCF. Synchronous traffic takes over the channel over asynchronous traffic through PCF.

3. Adapters of IEEE 802.11 MAC

From the above brief introduction of IEEE 802.11 access mechanism, we notice the following parameters that can be dynamically varied to achieve an optimal network performance. Following [3], the following are the parameters used in the implementation of adaptive MAC.

(a) *Inter-frame space*: The station waits for inter-frame space time and then sends the frame. In DCF, DIFS is used before sending RTS/DATA frame and SIFS is used before sending ACK/CTS frame.

(b) *Back off increasing factor*: It is a scaling factor for contention window (CW). In DCF mode, when a collision is detected (no ACK is received), CW will be scaled by a backoff-increasing factor and new backoff time (BT) will be chosen again.

(c) *Minimum and maximum contention window size*: To avoid collision, the DCF mode randomly chooses the BT from the interval (0,CW). CW is the contention window size and CW is in the interval of $[CW_{\min}, CW_{\max}]$.

By properly assigning different $CW_{\min}$, $CW_{\max}$, backoff increasing factor, we can prioritize the traffic. The following are the different adapters [1] we have implemented:

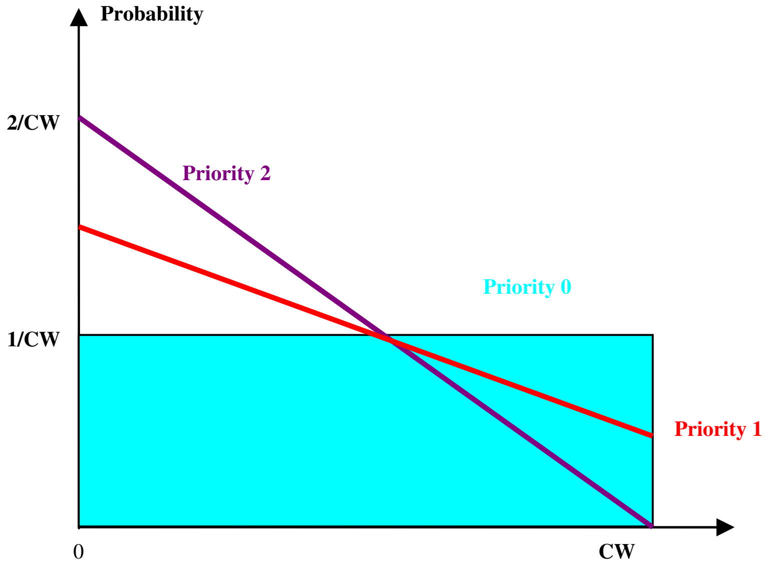

Fig. 1. Modified backoff distribution.

(a) *Contention window adapter* (*CWA*): Higher priority traffic should have smaller contention window size.

(b) *Backoff factor adapter* (*BFA*): Different priority packets have been assigned different backoff increasing factors. This adapter sets small backoff-increasing factor for high-priority traffic as follows: BIF is 2 for priority level 2, 3 for priority level 1 and 4 for priority level 0.

(c) *Backoff distribution adapter* (*BDA*): This adapter defines different backoff time distributions for different priority levels as shown in Fig. 1 where priority 2 is assigned to video conferencing traffic, priority 1 is assigned to HTTP traffic and priority 0 is assigned to e-mail traffic. By using different distributions, statistically high-priority traffic may have better chance to choose small BT than the low priority traffic.

(d) *Inter-frame space adaptor* **(***IFSA***)**: By this adapter, high-priority traffic may have smaller IFS than the low priority traffic as follows where j is the priority level:

$$DIFS_j = DIFS + slottime * (2 - j), \quad j = 2,\ 1,\ 0. \tag{1}$$

4. OPNET simulation

OPNET version 10 was used for running our simulation. Three different applications HTTP, e-mail and video conferencing are configured such that video conferencing has the highest priority, then HTTP and the least is the e-mail application. This priority assignment can be done easily in OPNET by assigning different type of service values in application definitions. At MAC layer by reading these types of service values, different adapters are designed. Values for the adapters are taken from [1].

4.1. Traffic models

Every mobile station can initiate simultaneously any of the above applications. All stations are identical in terms of traffic load. No mobility is assumed. Moreover, it is assumed that the server is located in the access point and it can provide all three applications.

Video conferencing: Frame size is fixed at 500 bytes. The inter-arrival time is assumed to be uniformly distributed (0, 25). The start time for the incoming video frame is computed by adding the inter-arrival time to the pervious video frame completed.

E-mail: A fixed size e-mail messages of 100 bytes each are generated where the inter-arrival time is uniformly distributed (0, 30).

HTTP: http1.1 is used. The page inter-arrival is assumed to be uniformly distributed uniform (0, 1). Moreover, each page has the following properties: header file (html base file) is 1000 bytes, and a medium image composed of five objects. The size of each object is integer and uniformly distributed (500, 2000) bytes.

We modify the wireless LAN model in the OPENT into an extensible architecture by implementing the *CWA*, *BFA*, *IFSA*, and *BDA*. In order to study the effects of each adaptor to support prioritized service, we change the setting of adaptors to study the performance. Table 1 shows the IEEE 802.11 direct sequence spread spectrum OPNET simulation parameters when no differentiation is applied.

5. Results and discussion

Extensive simulation runs were conducted and due to the space limitation, we shall limit the discussion to only few performance results under data rate of 1 and 2 Mbps and for different number of mobile stations.

First, we compare the throughput of different adapters. Fig. 2 shows interesting results where the throughput for CWA drops by 3% compared to IEEE 802.11. This can be attributed to the delay caused by prioritizing the traffic which will invoke the TCP congestion control and lead to the delay shown in Figs. 3 and 4. On the other hand, Fig. 5 illustrates that almost all schemes achieve identical throughput under 2 Mbps data rate. Thus, increasing the date rate may preclude the expected benefits from these new adapters. Also, we can observe the drop in the throughput as the number of stations increases and this is due to the contention among the users for limited bandwidth.

Table 1
Simulation parameters settings

Parameters	Values
DIFS	50 μs
SIFS	10 μs
Slot time	20 μs
Maximum retry limit	7
$CW_{\min}$	31
$CW_{\max}$	1023
Backoff increase factor	2

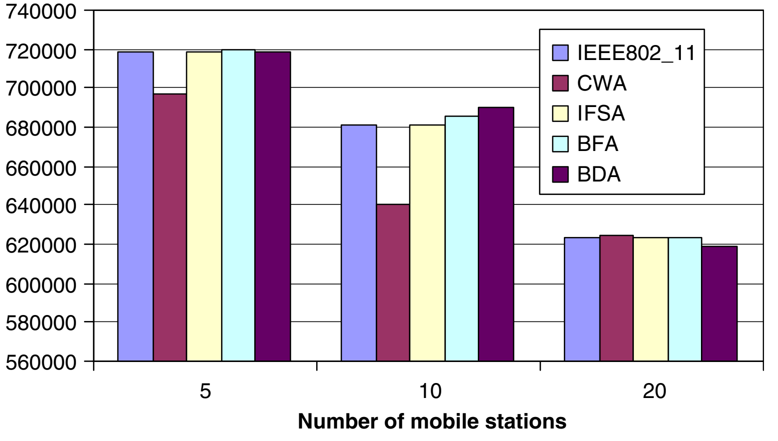

Fig. 2. The average overall throughput (bit/s), $R = 1$ Mbps.

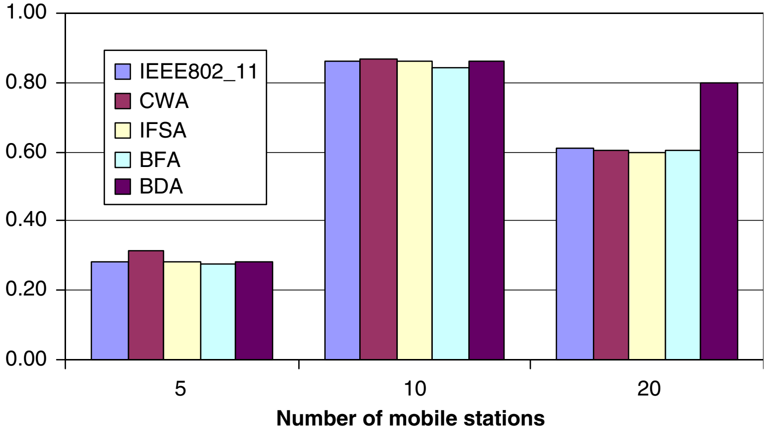

Fig. 3. HTTP page response time (s).

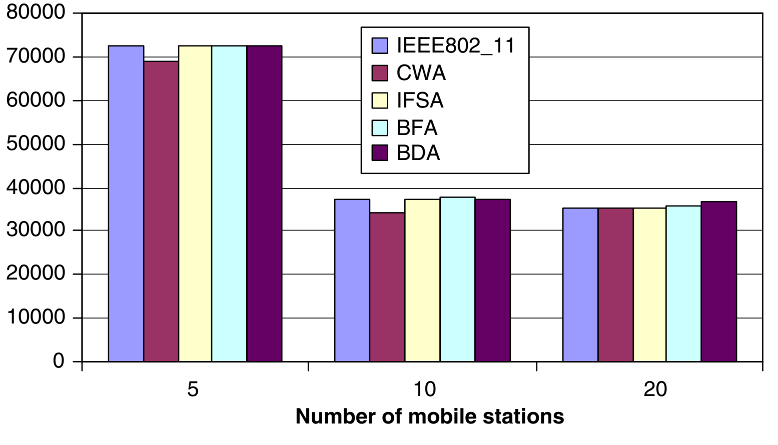

Fig. 4. HTTP received traffic (bytes/s).

Next, we study the medium access delay and the end-to-end delay for the video conferencing traffic. From Fig. 6, we can tell that at low traffic, BDA causes the end-to-end delay to be doubled and this is due to the conservative policy in assigning the backoff slots. However, at higher loads, all schemes have identical performance.

Considering the performance of e-mail application, Figs. 7 and 8 show that this application had suffered the most among the three applications. Also, under CWA scheme, e-mail suffers high delay compared to IEEE 802.11. Moreover, these performance results reemphasis the above-mentioned issue that under BDA, the Internet applications suffer the highest delay.

Finally, we look at the total number of backoff slots at the access point for all schemes. Fig. 9 illustrates that under low-load conditions, CWA provides the least number of backoff slots while at high load all schemes behave almost the same.

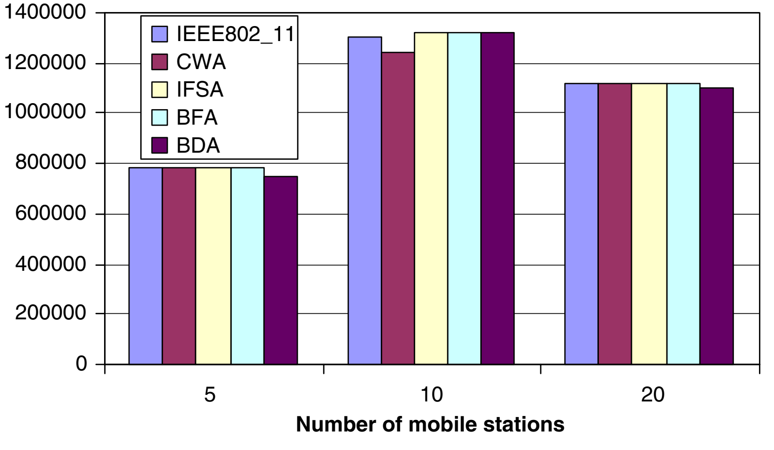

Fig. 5. The average overall throughput (bit/s), $R = 2\,\text{Mbps}$.

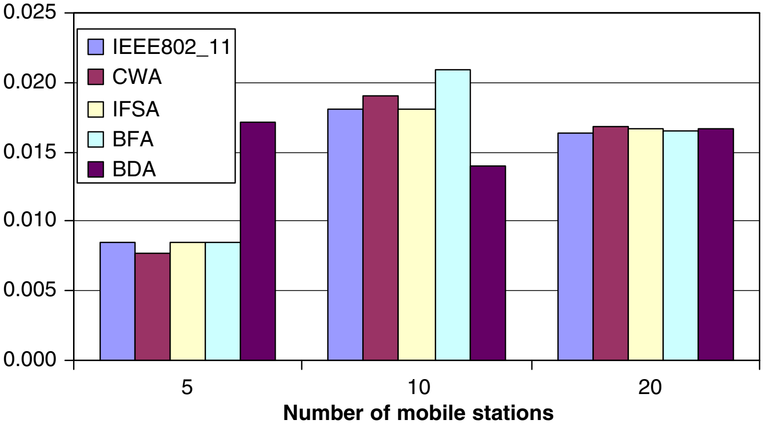

Fig. 6. Average end-to-end delay for video conference (s), $R = 2\,\text{Mbps}$.

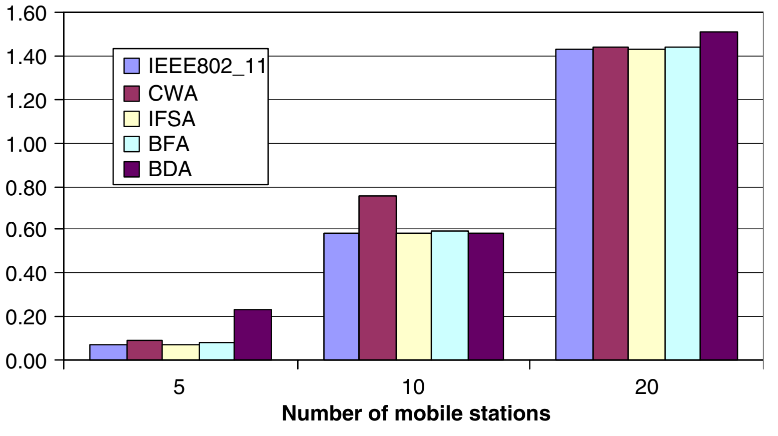

Fig. 7. Average e-mail upload response time (s), $R = 2\,\text{Mbps}$.

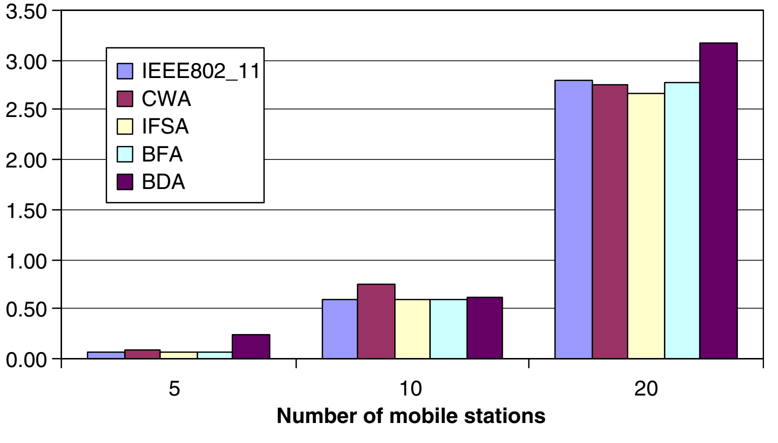

Fig. 8. Average e-mail download response time (s), $R = 2\,\text{Mbps}$.

6. Conclusions

In this work, the performance of Internet applications such as web browsing over an adaptive prioritized IEEE 802.11 MAC architecture was studied. Several adapters were studied using OPNET simulation where several scenarios of WLANs operating at 1 and 2 Mbps transmission rate were conducted. Three competing applications were studied, namely video conferencing, www and e-mail. To ensure the adaptive nature and simplicity of the adapters, prioritization is implicitly applied without any intervention from the network operator. By means of throughput, media access delay, http object response, end-to-end delay and other metrics, the performance of the network under study has been evaluated. The results show, in contrary to the previous published results [3], that no clear conclusion can be driven out of these adapters. The results also show that the operation at high traffic load will have drastic effects on http application which manifest itself in very

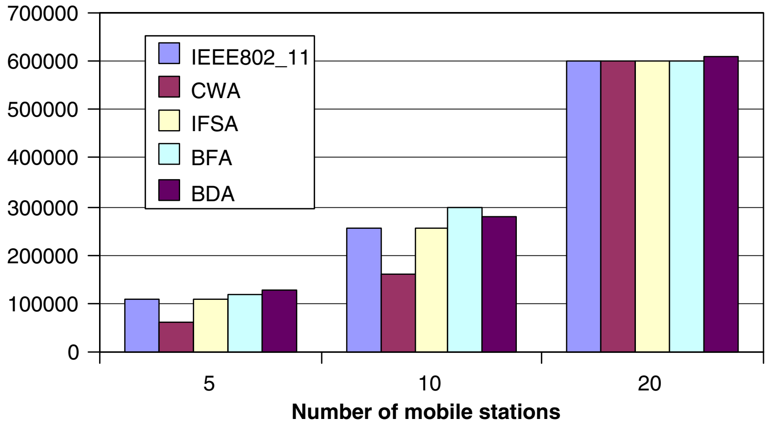

Fig. 9. The average number of backoff slots, $R = 2\,\mathrm{Mbps}$.

low throughput for such application. In conclusion, the network operator must be very careful in applying these adapters, especially when real-time application traffic load is high.

Acknowledgment

The authors wish to acknowledge the support of King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia during the course of this work.

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